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Requirements Capture and Analysis for a Decision-Aiding Application

J.P.A. Smalley
DERA Malvern
St Andrews Road, Malvern
Worcestershire WR14 3PS, England
e-mail: jpasmalley@dera.gov.uk

Summary: This paper is about human factors integration, and providing information displays to match the operators' requirements. It addresses Man-Machine Interfaces and visualisation techniques. It will describe a method of requirements capture that translated into highly acceptable and very effective information displays.

Background: The main background to this analysis methodology comes from two projects that have been conducted at DERA Malvern. Both projects were about developing a decision-support system. The task for which this system was required involved detecting threats, identifying their nature, tracking them and predicting their implications and the hazards they posed. The decision then concerned what resources to assign against the threat, and when. This required information about what resources were available and against what they might be allocated.

The Human Computer Interface (HCI) implementation for one system was strongly legacy-system based, with well-established functionality that simply had to be re-implemented with new technology, refining an existing task. The other, new application had a well defined purpose, but no functionality defined at the outset, and required development from nothing.

The decision-support requirement: Both of these projects were essentially about providing decision-support. For the newer Athena project this focused on the weapon allocator's rôle. The weapon allocator's task is to decide what response is required and to select the counter-weapons from those available. The decision-support system provides the overall tactical picture on a graphical map display, showing the options and intercept progress on an associated display. This provides the necessary information to select a weapon, displays the information reported back on engagement status, and enables subsequent shots to be scheduled and taken. The interface provides the facility for the allocator to transmit the weapon-firing request to the weapon controller.

The prototyping philosophy for this project, exploited a skeleton set of phases and modes of command and control against which to assess an offered solution for acceptability.

The legacy system: This was a capability maintenance project for equipment that required replacement — with the emphasis on exploiting commercially available technology. From a survey of what new technology could offer, coupled with a review of existing standards, a set of Guidelines was produced for implementing the replacement system, validated by prototype demonstrations and implementations for operational service.

Their aim was to aid the production of HCIs with effective handling and display of computer generated information. These included displays of graphical and tabular information, graded according to urgency,

enhanced by symbology and colour, and supplemented by other media. The Guidelines also contain further information that impacts on HCI design, for example:

- operator rôle and target audience descriptions;
- impact beyond the work-station, *e.g.* the console design or control room layout;
- particular implementations identified as generic components, *e.g.* communications control panels; or
- particular implementations for specific operator rôles.

Two factors drove their further development. Whilst the existing Guidelines, for the most part, addressed a specific problem, it was fortunately one that comprehended whole control rooms. This meant they could be applied to other systems as a default solution with particular differences resolved by exception. There were several such applications for which the Guidelines were perceived to be relevant. To be able to mandate the Guidelines for future procurements, they would have to be interpreted for each new application. This in turn demanded a requirements capture and HCI assessment methodology to do this. The "greenfield site" Athena project provided the basis for the answer.

The Athena (greenfield) system: The Athena project began with no such functionality constraints. The objective was to build a Command and Control (C2) demonstrator for a decision-aiding system for anti-ballistic missile weapon allocation and control. The threat was well enough definable, but had not been translated into functional requirements: the tasks to support those functions were completely undefined. The Athena HCI Assessment Suite was evolved to provide the necessary requirements capture methodology for this project and to develop the highly useable, internationally demonstrated interfaces. Subsequently, the opportunity arose to develop this requirements-capture and HCI-assessment methodology and harness it to the Guidelines for how to use the technology derived from the legacy system project, in order to exploit the synergy and produce a generic HCI-analysis-and-design package.

The Guidelines comprise the following components:

1. Guidelines for the Guidelines (why and how they should be used);
2. generic core guidelines;
3. annexes and case studies;
4. assessment methodology.

It has been said that Command and Control is the glue that holds a system together — a system being defined as collection of separate components that are connected together. These cover aspects of the operator rôle (*e.g.* receiving briefing, detecting targets, prosecuting targets and reviewing task success) that are affected by the system context and, conversely, aspects of how the operator contributes to the specific functioning of the equipment through the generic tasks of direction, control, monitoring and appreciating the situation.

Figure 1 illustrates some of the component tasks required by such operator rôles. Here, performance information is derived from performing the task — from the attempts to perform the required functions. Not all performance information is relevant. The reporting criteria represent the questions while the reports represent the assessment results about interference with other ongoing plans. These intentions may be encapsulated in a user guide, which describe what the system is supposed to do.
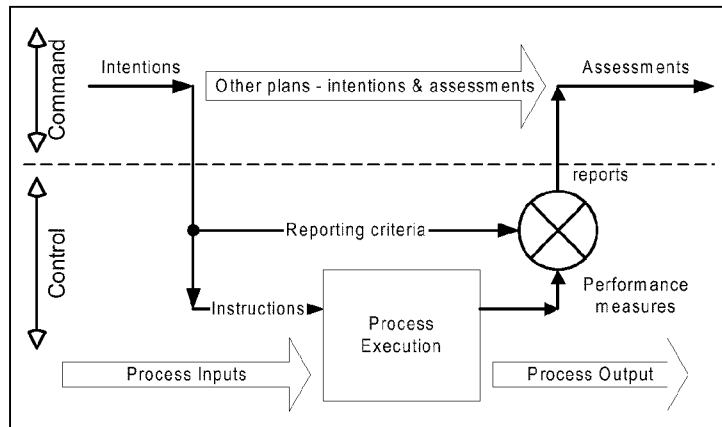
Figure 1. Elements of command and control

The point to develop here is that there are a number of generic human contributions to a command and control system by which the command node occupied by an operator rôle may be analysed. These generic command nodes or operator rôles are:

- command (and planning);
- communications (information exchange and status reporting);
- navigation and piloting;
- tactical situational awareness;
- system operation;
- system monitoring (alarms, alerts and warnings);
- operational co-ordination.

These operator rôles or command nodes then become the components that are held together by the command and control system. There is primary command requiring general situational awareness and planning of operations. There are communications with outside parties, both receiving information and transmitting. There are surveillance and watchkeeping tasks with tactical situational awareness. There is the notion of navigating, which may be position-plotting, course setting or directing the plan of execution. There is system or equipment operation. There is system monitoring with the associated alarms, warnings and alerts. There is the need to support internal co-ordination. All of these are aspects of the operator rôles that define the functional requirement for the work place and workstations. These must be designed to accommodate the potential operators who will perform their rôle or rôles there.

Principal system functions

The following are the principal system functions for applications with which a typical C2 system must integrate, both in terms of sources of command and items for control (see Steinhausen et al, 1978):

- command and communications, *e.g.* radio
- prime task integration, *e.g.* gun, missile launchers
- manoeuvring and transportation, *e.g.* tractors and trailers
- environmental defence, *e.g.* weather protection
- common support, *e.g.* power supply
- life support and habitability, *e.g.* clean air
- system monitoring, maintenance and repair, *e.g.* food, sleep

These are imbedding dimensions that are both mission and system related. This is because the system (and its operator interactions) must be justified by its mission purpose — there must be a reason for why it is there. Equally, by continuing to ask the question 'How?' — 'rolling in' — the answers, which define what the system must support, will fall naturally into these categories.

For instance, these principal system functions provide categories for analysing system failure effects and their impact. The design implications are then to determine what can be done to defend against such failures by preventive or corrective measures, and to assess the importance of doing so. Thus, these "system functions" provide a basis for analysing the "total system" requirements for operator interactions, both in terms of their environment and the systems they control. They can be analysed according to how the command and control system will orchestrate the concerted operation of what has to be done (jobs, tasks and functions) by their constituent components (people, missions and technology) in order to achieve the required purpose of the whole organisation.

The design process

The philosophy of the system evolution process must take into account two components: the abstract and the real system implementation. The design process for a workstation or console is naturally iterative between these two aspects, if only because at the outset the user does not know what is technically feasible, nor does the technologist know what the user might require if he knew what could be provided. As far as a system manufacturer is concerned, the human contribution to its operation is firmly in the abstract realm — just as much as, say, integrated-circuit design or software code is beyond the real world of those who use the equipment. However, from a total system perspective, there is some overlap between these two, where the human comes into contact with the equipment – the so-called "man/machine interface". On one side of this contact area, the system must be integrated (the HCI); the human must adjust to the situation (the Human System Interface (HSI)) on the other. These different interests and their implications for integrating Human Factors into HCI design are described elsewhere (see Smalley (1997)).

At this point it will be helpful to distinguish between super-systems that contain everything that is subject to design, and sub-systems with respect to the HCI system design. The super-system is the context which drives the requirement (and is itself driven by its invariant hyper-system — the system in its most extended form, which provides the fixed context for the whole system implementation), whilst sub-systems contain the sets of co-ordinated elements for performing the tasks. This gives the following five-layered model:

1. hyper-system;
2. super-system;
3. system;
4. sub-system;
5. component elements.

The hyper system, super system and system levels relate to the abstracted environment; the system, sub-system and system elements relate to the real components.

In terms of implementation, this translates into three levels of interest, working outwards from the technology behind the hardware (levels 5, 4 and 3), to the operator at the console or workstation design (levels 4, 3 and 2) and then the operational context of the user, which is bounded by the control room (levles 3, 2 and 1). The prototyping process then allowed the system design to be drawn out, using a skeleton set of task phases and modes of command and control to draw out the required system operations and to assess the design concept for acceptability.

The Athena design evolution used an iterative process of designing a little and building a little, then running an operator-assessment trial to ensure that, with each step, the evolving design remained on course towards the end design. Thus each instance provided the stimulation to determine the way forward and take the system design from abstract concept to tangible execution.

Figure 2 depicts the iterative nature of the system design process for human interaction at any particular level of hyper-system and sub-system. Here, the console issues pivot between the hyper-system beyond the control room and the sub-systems of console components — between requirements set by the super-system and specification of sub-system components. This describes five major phases in this process: primary requirements capture (1-2), derivation of constraints and secondary requirements (2-3-4 and 8-4), feasibility checking (4-5), implications for host organisation (criteria of acceptability: 5-6-7) and design specification (7-8) leading to requirement definition for next level of detail.

Figure 2. Analysis and design iteration

The draft system requirement and criteria are determined at (1). This is the requirement identified at the super-system level to fulfil the task, concentrating on the functional requirement.

The component functions (I/O signals) are drafted at (2). This translates the functional requirement into a functional specification at the component level.

Derivation of constraints and requirements: Model implications are derived at (3). This prototypes the subsystem by whatever models or simulations are appropriate for the purpose of representing it — in order to produce the information which will enable discrimination between alternative options for final implementation.

Feasibility checking: The feasibility that the system will work, as a function of its component behaviours, is assessed at (4). This concerns whether the components will live together compatibly. The check on system implications at (5) concerns whether the output of the subsystem is compatible with the requirement imposed by the super-system.

Implications for host organisation: It is necessary to agree or confirm the system interface at (6). Once satisfied that the super-system requirements can be met by the proposed system design, this is confirmed, so that the super-system can be reconfigured to receive the new system and its sub-systems.

Specify design: The system design stage entails refining the component options and specifying the system when down to one option at (7). If any options remain at (8), then iterate from (3) with model implications, determining feasibility, *etc.*

Command structures and decision nodes

Since the design process is in itself a decision process analogous to command and control, it should be possible to map across to a generic command and control structure.

There are two types of command and control: one has the command structure embedded in the system components, and is therefore real to the controlled system. For the other type, the command system is hosted by a separate entity (for example the people in an organisation) from the controlled system to which it is connected by formal, specifiable and configurable links or communication channels, and is therefore abstracted from the real system.

Figure 3 is an information flow diagram that illustrates some important aspects of the system of controlled functions that link the generic command nodes identified earlier. This shows the whole process running from primary situational awareness at the top left to internal system co-ordination at the bottom right.
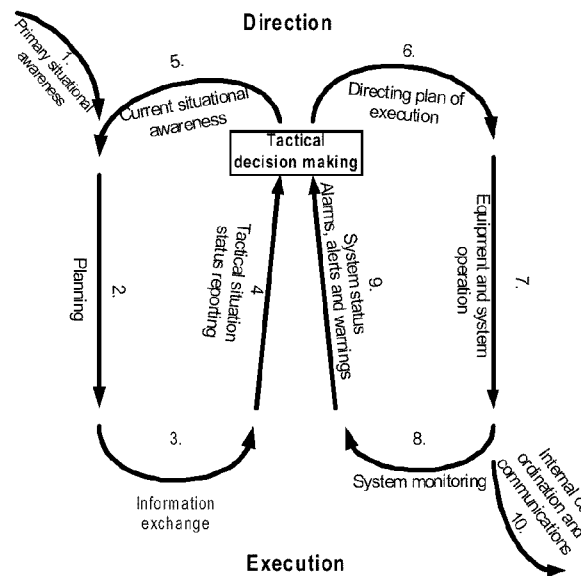

Figure 3. The C2 modes for tactical decision making

The left half of this diagram is concerned with the driving influences of the outside world. In the field, these are appreciated by commanders: they are analysed to generate the operational and functional requirement for the system. The right half is concerned with the system under control (whether for real or as a technical specification). The upper half is concerned with command and direction: the lower half is concerned with the execution and implementation of the system purpose. The flow lines in this diagram represent or provide for either of two processes:

1. the thinking processes or modes of using the information in a command and control system;

2. the sequence for analysing, designing and implementing a system.

These C2 modes (as opposed to the nodes described earlier) are as follows.

1. **Primary situational awareness** is concerned with answering **why** is this system here and doing what it is doing. It is concerned with collecting all the information that focuses on this answer.

2. **Planning** is concerned with taking in the current state of the mission field and determining what aims to drive for. This combines the why of primary situational awareness with the where of current situational awareness as the basis for deciding what the future targets should be and how to get there.

3. **Information exchange** is about **who** the other players are, what they might be doing and what their intentions might be.

4. **Status reporting** is about the end-point status of the mission field and players.

5. **Current situational awareness** is about maintaining awareness of the immediate state of the mission field — locating **where** specifically items are. This information merges with the primary situational awareness to drive the planning process (C2 mode 2) whose output may then drive the information exchange with other players and comes out with the status plotting and reporting of mode 4.

6. **Directing plan of execution** is concerned with **when** events are to happen, cued by the status of the mission field and conditioned by the state of the available technology.

7. **Equipment and system operation** is concerned with the hands-on operation in response to the directions from mode 6. This mode concerns the specific protocols, sequences of operation and the dynamics of control or perception required to control the equipment.

8. **System monitoring** concerns the process of maintaining general awareness of system performance and capability, of what reserves are left and of approaching decision points, danger areas *etc.* — in order to sustain the intended programme of action.

9. **Alarms, alerts and warnings** concern the feedback of system status information which might change the ongoing plan of execution.

10. **The internal co-ordination and communication** mode is about the internal comms system for liasing with other systems under control, for re-configuring the system, re-loading new software, stage changes, etc. This mode concerns the command of **how** the system is configured to achieve the desired results.

As the project progressed, and the HCI concepts evolved, it became possible to translate the skeleton command and control structure and decision-making requirements into the specific tasks, shaped by the particular implementations and applications. In other words, the analysis began with the generic man-centred task and then added the implications from the mission context and the technology available. This led to the specification of the system requirement. This also allowed variations in scenarios and the state of the operator to be taken into account.

The rating methodology

A progression of assessments was developed so that each provided relevant training or briefing for the higher-level assessments and requirements capture to follow. These comprise the Athena HCI Assessment Suite (see Smalley, 1998).

There are two sides to rating the HSI for decisions. These are the consequences in terms of the importance to the task. The other is in terms of the quality of the equipment interface provided to support the decision.

The Cooper-Harper rating method: At the heart of the assessment methodology is a modification of the well-established Cooper-Harper rating scale. This provides the thinking tool to take a particular task and assess the utility of the equipment offered to support that task. The ratings range on a ten point scale from something like fatal consequences to certain and effortless success.

The original Cooper Harper scale, was developed for aircraft handling assessment — it was developed by George E Cooper of the Ames Research Center, Moffett Field, California, and Robert P Harper Jr of Cornell Aeronautical Lab Buffalo, New York. Essentially, their rating method provides an algorithm for the operator to answer questions about the function under assessment until reaching a score, which is the assessment rating. The rating is obtained through three dichotomous decisions about the equipment under test for the task:

1. controllable/uncontrollable;

2. acceptable/unacceptable; and

3. satisfactory/unsatisfactory.

This is followed by a progressive refinement of the assessment. At no point is the required discrimination more complex than a good, bad or indifferent rating, and the resulting scores may be interpreted according to the table shown in **Figure 4**.

Score	Acceptability	Applicability
1-3	Satisfactory	Normal use
4-6	Unsatisfactory	Emergency use
7-9	Unacceptable	No operation
10	Fatal/uncontrollable	

Figure 4. Interpreting the Cooper-Harper scores

In summary, the C-H assessment technique provides a formal operability rating of the interface, in a way that is useful to the development of the interface and decision aiding equipment. This technique does not measure how well the operator can do, but produces a rating that can be translated into specific sentences about whether specific tasks can be routinely performed to specific degrees, i.e. it is a rating of the interface, using the operator as a measure.

These ratings were useful for two purposes: to check the completeness of the requirement capture, and to prioritise where development effort should be applied by producing a "maturity profile" to give an indication of how much further development effort might be required. This is important to indicate how far down the line an acceptable solution may lie.

Maturity of concept and design: We discovered that diverse ratings reflected unclear definitions of the task's purpose. Hence the tool could be used to focus attention on where clarification was needed from the expert users. Once the task was clearly defined (as a user guide for instance) a remarkable consistency of scoring was achieved. (See also Harris *et al*, 1998).

Analysing the rating: Whilst the C-H assessment gives a rating which relates directly to the importance of improving a function for operational purposes, it does not specify the nature of the improvement which might be needed. The important point here is that the C-H rating concept was extended to capture the reasons for the imperfection by asking for comments to defend the rating applied, locating where the specific difficulties occurred in the successive stages of making the decision — see **Figure 5**.

	Task	Psychophysical issue
1.	Monitor and detect	(signal detection)
2.	Identify and classify	(perception)
3.	Associate and correlate	(interpretation)
4.	Connection of meaning and decision taking	(execution)
5.	Response and action	(action)

Figure 5. Stages in making a decision

There is not time or space to pursue this in detail here. Suffice it to say that, for any decision-making function, the HCI could be rated for all its phases of operation for each of the different modes of command and control. Ratings and comments could then be merged and consolidated requirements could be obtained. This gave a clear indication of what needed to be done to move the design towards perfection — or at least a rating of 1-3.

Conclusion

In conclusion, the methodology that evolved has provided the basis for a generic C2 requirements capture and analysis tool, which has been refined and included for use with the HCI Guidelines developed at Malvern for future military airspace management systems.

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